Early hydro-electric power plants at Niagara

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The Adams Power Station

Although there had been various small hydro schemes for local industry use prior to 1890, the first significant plant generating electricity and transmitting it over some distance to Buffalo was the Edward D Adams station. This was built on the US side of the Niagara river upstream of the American falls and started generation in 1895.

It was the largest hydro power station in the world at that time producing about 37MW when all ten turbines were in operation. This does not seem very much power from the perspective of today and indeed larger stations followed quite quickly. Power was first transmitted to Buffalo in 1896, which was also a landmark achievement.

The splendour of the falls and the sheer mass of water involved had made Niagara an attraction for visitors for years – and caused many to wonder how to harness some of the immense power potential in a significant way.

Figure 2 The Adams Power Plant before most of it was demolished. The transformer house is seen centre-left.

My son and family live in Ontario and we visited the falls in March 2018 with the landscape covered in snow adding some magic to the scene. There were some ice formations near

Figure 1 Aerial view of the Falls – the present day
The Canadian side is to the bottom of the picture next to the horseshoe falls, with the American falls next to the promontory at the top – with the relatively straight lip. The "Maid of the Mist" is also clear.

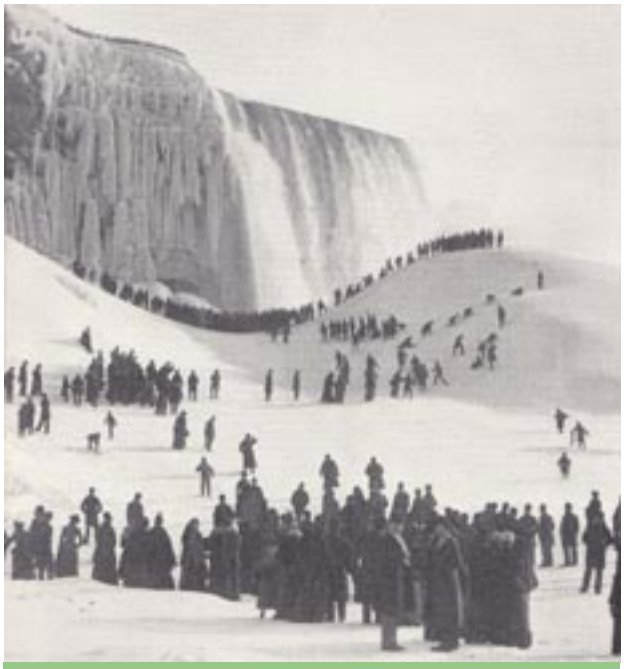

Figure 3 Ice Bridge under the Falls circa 1890

the foot of the American Falls – but nothing like as spectacular as shown in Figure 3, taken in about 1890.

In 1889, the Cataract Construction Company was formed to develop the hydro plant named after its president, Edward Adams. Other notables who acted as officers or directors included wealthy men such as Pierpont Morgan, William Vanderbilt and J J Astor, as well as William Rankine, of which more later. There was a hope of transmitting power as far as New York City from the early hydro stations - which had been suggested by Nikola Tesla.

Edward Adams, whilst in Europe in the winter of 1890, astutely established an International Niagara Commission in London to obtain the best information on hydro power schemes from all round the world – much of it not necessarily in the public domain.

To encourage people to share their experience and put forward new ideas, prizes of up to US$22,000 were offered. The commission included such notables as Lord Kelvin, as well as engineers from France and Switzerland with experience of alpine hydropower projects.

Figure 5 International Niagara Falls Commission
Prof R Mascart/Prof W C Unwin/Lord Kelvin/
Dr Coleman Sellers/Col Th Turrettini

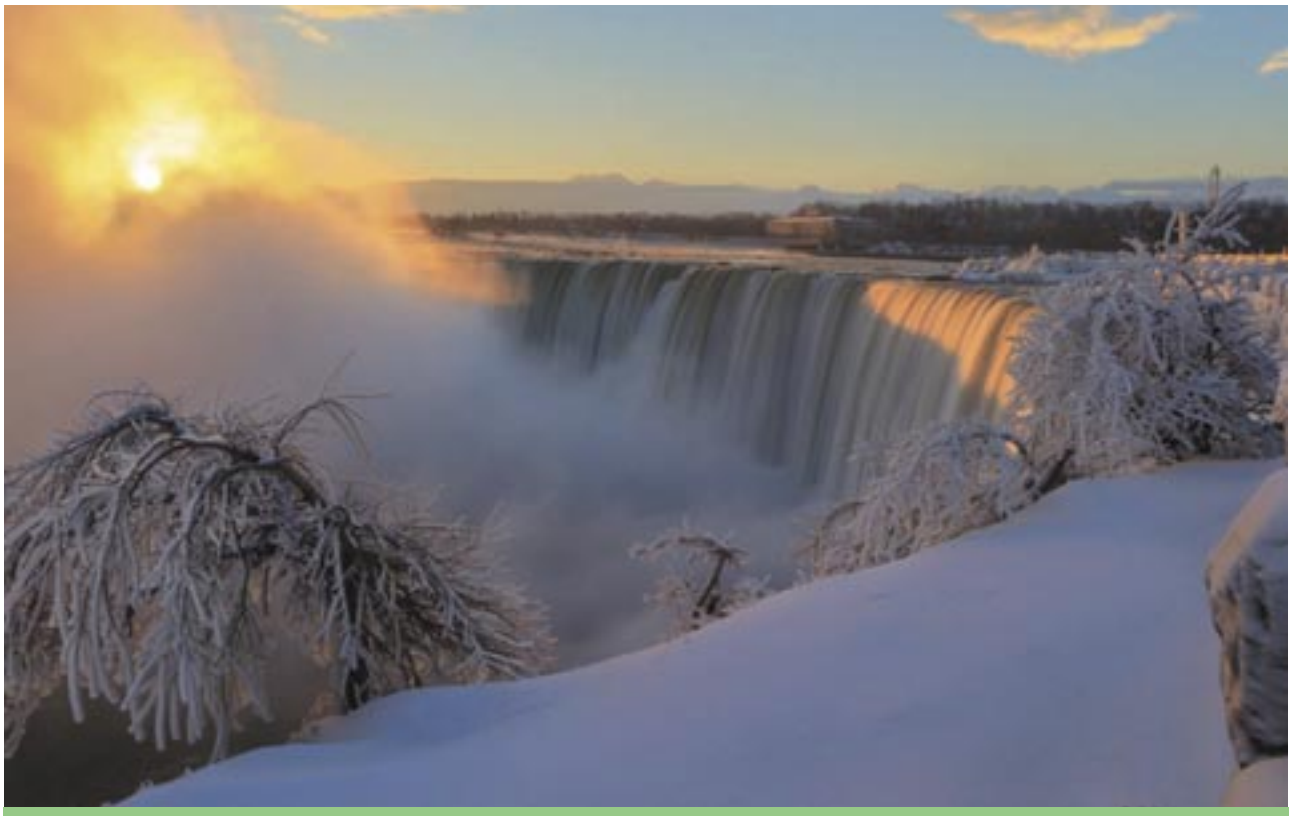

Figure 4 Sunrise over the horseshoe falls in winter - present day -
derelict power house of Toronto Electric Power seen upstream of the falls

It was already clear that the "hydro wheel" makers in the US had no experience of the high flows and head that were available at Niagara, but several Swiss manufacturers had the relevant experience. In the event, the bespoke turbine design was done by Faech & Piccard in Geneva and the machines manufactured by I P Morris in Philadelphia.

However, the main uncertainty was how to transmit power to remote locations - since local demand was nothing like large enough. Advice was sought from many people in the embryonic power industry – some of whom went on to become very important in this sector in the 20th century.

Earlier hydro-projects in Europe and the US had used power transmission by wire rope, hydraulic pipes and pneumatics, the latter at distances up to 7 miles and powers up to 7,000hp in the case of the Paris pneumatic system. Even George Westinghouse proposed pneumatic transmission from Niagara to Buffalo – admittedly in 1890 before the Commission's work had begun.

The superiority of electric transmission was illustrated by Ferranti in a debate in 1890 where he proposed high voltage transmission as a means of reducing losses over long distances. By 1895, Nikola Tesla was predicting commercial delivery of 100,000hp to New York, 450 miles away from Niagara – and even further to Chicago – using high voltage AC and transformers. Successful electric transmission had also been demonstrated in Europe and the US, but not on a scale suitable to Niagara's power and the distances involved.

Perhaps the most curious decision to modern eyes was the adoption of 2 phase alternators generating at 25Hz. These were 5,000hp (3.73MW) each with the field magnets rotating around the static armature under a large bell-shaped housing rotating at 250rpm. This provided a significant flywheel effect, but also gave rise to some concern about the integrity of the bell housing.

Figure 6 A field ring ready to be lowered onto a generator shaft

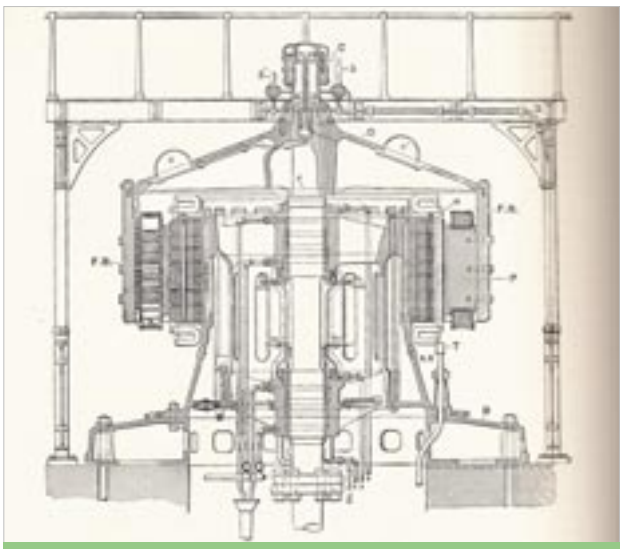

Figure 7 Vertical section of one of the 5,000hp generators

Figure 8 During the 1950s all of Ontario was systematically converted from 25Hz power to 60Hz power. Trucks like those shown here came through each neighbourhood converting motors to the new frequency. You'll note here the sign on the truck "60 cycle power for progress".

The ten alternators at the Adams plant were made by Westinghouse.

The repercussions of the choice of 25Hz were extraordinarily long lasting in Ontario with distribution at 25Hz continuing until the 1950s.

There was much debate about whether hydro electricity from Niagara could compete with steam power from coal generated closer to demand centres. Both technologies were in their infancy – and coal was plentiful and cheap. So an early Renewables vs Fossil generation debate was very active even then – and Edison bought the steam turbine patent from Curtis in 1896 to underline this.

Because all three of the early stations were located above the falls, they involved deep wheel pits (140ft at Adams) with long shafts between the turbines and the generators at the surface.

Later stations such as the Sir Adam Beck I (1923) were downstream of the falls with the powerhouse near the river below the penstocks allowing turbines and generators to be close coupled.

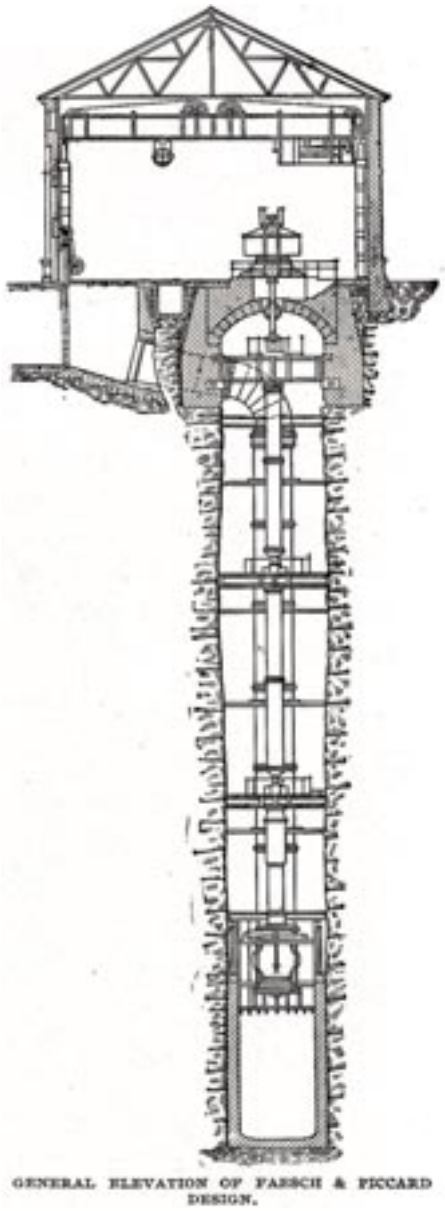

Figure 9 Vertical section including the extraordinary wheel pit – Adams Plant

Power from the generators at the Adams plant was cabled to an adjacent building housing the step up transformers in a 2 phase, 4 wire arrangement - which was converted to a 3 phase, 3 wire arrangement at up to 20kV for transmission to Buffalo by centre tapping on the HV side.

The photo of the first transmission line shows this arrangement which saved a considerable amount of copper employed along the 25 miles to Buffalo (see Figure 11).

Progress on the Canadian side

Rankine Generating Station - 100 years of power generation

The Rankine story really begins in 1889 with the formation of the Niagara Falls Power Company in New York. Initial plans for this company were to produce electric power on the US side of the falls, eventually at two plants - the Adams generating stations.

Logically, wanting to move into production of power on the Canadian side of the falls, a spin-off company called the Canadian Niagara Power Company (CNP) was formed in 1892. A site was leased from the Niagara Parks commission – eager to see development of the falls like that occurring on the American side – upon which the Rankine generating station was to be constructed for $25,000 (1892 dollars).

The agreement, designed to stimulate power production on the Canadian side, stipulated that construction of a power plant must begin by 1897 and by 1898 production of 25,000hp must commence – so unrealistic expectations at the outset are certainly not new!

By 1897 it became evident that CNP could not meet the deadline for development as the American arm of the company wanted to complete the Adams plant first - from which transmission of power to Buffalo began in 1896.

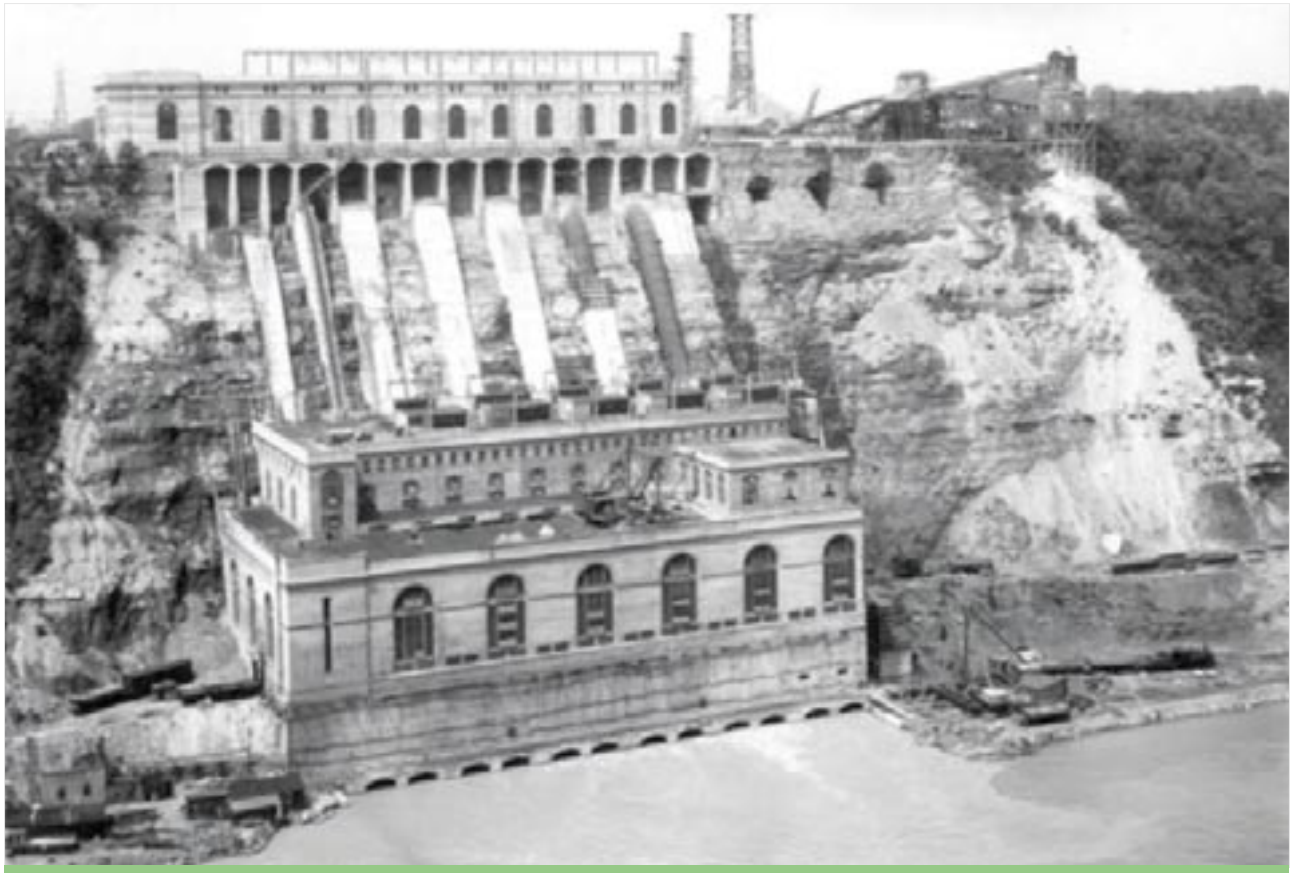

Figure 10 Construction at the Sir Adam Beck Power Generating Station - June 1923

A World Fair was planned in Buffalo before the end of the century, but it was delayed somewhat by the Spanish-American war which broke out in 1898 – and was eventually held in 1901. Unfortunately this exposition is probably best remembered for the assassination of President McKinley by an anarchist in September 1901.

Completion of the Adams plant first allowed the working-out of technological 'bugs' like lightning arrestors and switchgear before starting construction of the Canadian plant.

As a result of this experience, it was hoped that the Rankine plant would be planned better from the beginning - although 25Hz was still to be used since it was now 'standard' in the Niagara area. However, the alternators were 3 phase (instead of 2 phase as at the Adams plant) and generated at a higher voltage of 11kV to reduce losses.

Not surprisingly, local officials in Niagara Falls were upset at the apparent lack of (promised) investment in power generation – the whole idea of the agreement in the first place was to develop the Canadian side of the falls into a major power production centre, with the ultimate goal of providing power to the large city of Toronto.

By 1899 it was obvious that CNP could not supply power to Toronto (CNP had not even started construction of the

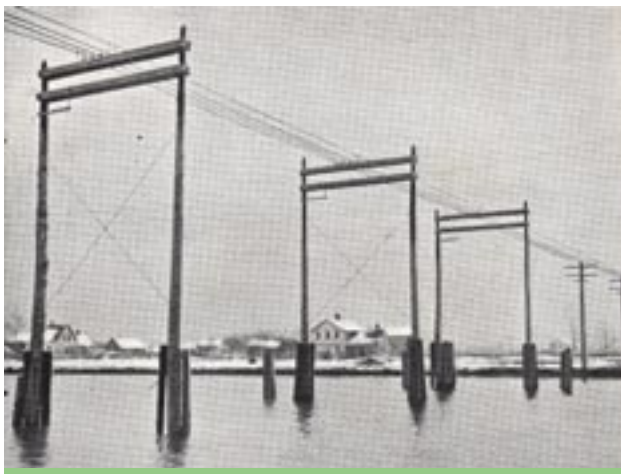

Figure 11 Crossing a creek along the Niagara-Buffalo transmission line

Figure 12 Rankine powerhouse with forebay, (current photo with high rise behind)

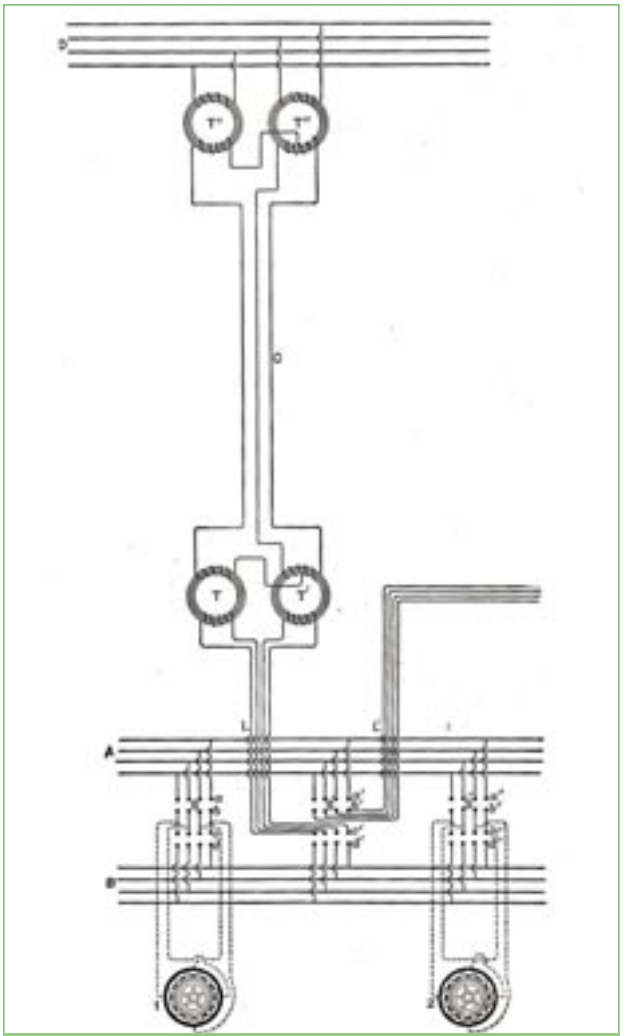

Figure 13 Diagram showing the connections of the generators with Local and Long-distance feeders

Rankine plant) and CNP's monopoly to produce power at the falls was lost, allowing other companies to compete. The Electrical Development Co (later Toronto Power) built a plant which began producing power in November 1906 situated a little further away from the Horseshoe Falls than the Rankine plant (which can be seen in Figure 12 in its derelict state).

To be fair to CNP, apart from the focus of investment and effort on the Adams plant, there were technical difficulties to overcome in the transmission of power to the intended loads in Toronto – sending power from Niagara to Buffalo was one thing (at the time, a milestone), but Toronto is considerably further away.

While the delay in building the Rankine plant proved costly to CNP in terms of losing its monopoly on power production, it also gave them time to overcome technical obstacles. By 1902, a year after construction of the plant began, the problem of transmission of power to Toronto was solved - accomplished by stepping-up the voltage to 60kV using transformers built by Canadian General Electric.

On 2 January 1905 the Rankine plant began producing power with two 10,000hp alternators. The total cost of the completed plant was $5.2 million (1924 dollars) – what do you mean, cost overruns!

Plant description

Water from the Niagara river enters the forebay to the plant just above the Horseshoe Falls. Ice has always been the achilles-heel of generating stations at Niagara and the Rankine plant used an icebreaker boat and even dynamite to clear the forebay from ice build-up. One of the features of the forebay was indeed the ice sluice which routed broken-up ice back to the river where it went over the falls.

The architecture of the plant with its huge arches and limestone construction does not detract from the aesthetic beauty of the falls. Huge copper doors on the other side of the plant allude to the grandeur of the building and the status electricity once had in the dawn of the electric era.

The quality of the first photograph (Figure 12) sadly doesn't do justice to the splendour of the building. A better quality photo taken in 1913 (Figure 16) gives a far better impression.

The Rankine generating station looks much the same today as it did in 1913 (Figure 12). Both Canadian Niagara and the commissioners of the Queen Victoria Niagara Falls Park worked hard to get the aesthetics right for the powerhouse

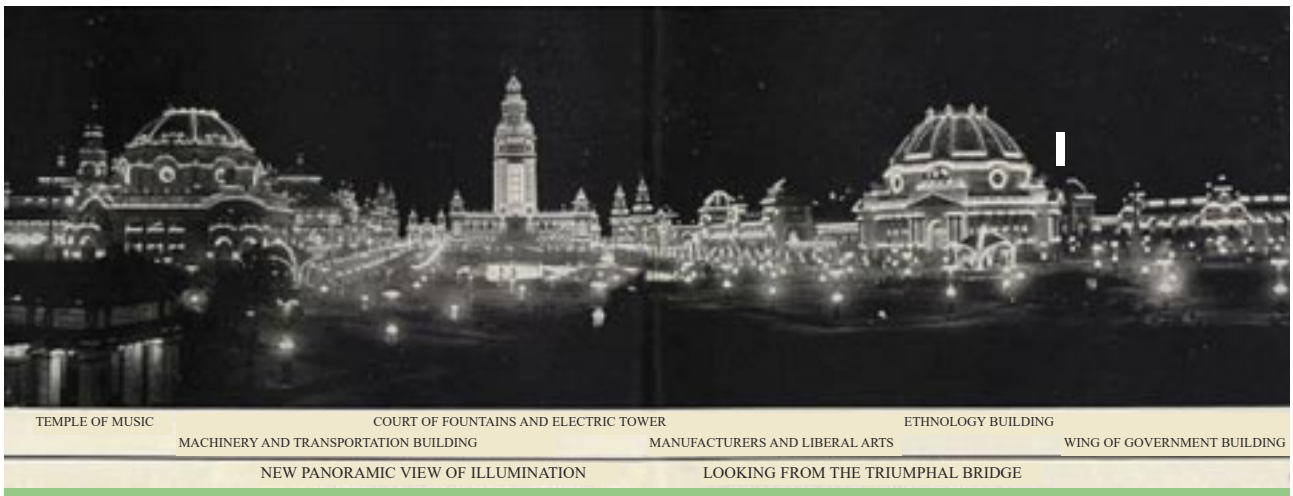

Figure 14 World Fair buildings illuminated 1901 – a spectacular example of the new electric age!

Figure 15 Entrance to the forebay from the Upper Niagara river

in a park. For example, to maintain the scenic integrity of the park site, there are no above-ground cables or wires running to or from the generating station.

Figure 16 shows the care, pride and expense that went into the construction of the plant - as well as the relative rural nature of the environment in 1913, which is a stark contrast to today. The aesthetics of some of the later developments at Niagara leave something to be desired – in particular, little "Las Vegas" on the hill overlooking the falls.

On 30 September 1905, William Rankine died, three days after the third generator was put into operation. In 1907, the Rankine Power Station provided the first electricity to the village of Fort Erie. In 1927, the Canadian Niagara Power Company powerhouse was renamed the "William Birch Rankine Power Station".

On completion of the plant, eleven generators produced 100,000 horsepower (75 megawatts). The generators have vertical shafts, wound for three-phase current, producing 11,000 volts of 25 cycle power at 250rpm.

The rotating turbines each turn a 40" diameter steel shaft and water after leaving the turbines empties into a 25 feet high – 2,200 feet long tunnel which discharges into the lower Niagara River at the base of the Horseshoe Falls.

The turbines, each of a capacity of 12,500 horsepower, were designed by Messrs Escher, Wyss & Company of Zurich, Switzerland, and are of the twin-Francis vertical type, inward discharge, two draft tubes to each unit discharging into the open tailrace below. Three of these units were manufactured and installed by this firm, and other units of the same design were installed by I P Morris Company of Philadelphia, PA.

Figure 16 Rankine Station in pristine condition in 1913 – a magnificent building

William Rankine was related to the more famous Scottish engineer William John Macquorn Rankine, after whom the Rankine Cycle and temperature scale is named – see the biography section in the appendix.

The Rankine plant was one of just four powerhouses, all at Niagara, that were ever built with such deep wheelpits (136 feet from generator to turbine, with another forty-some feet below that was given over to structural supports and the tailrace tunnel), and the only intact example remaining.

Over time, the long drive shafts that stretched back up to the surface fell victim to the movement of the rock surrounding the pit, shifting slowly out of a true vertical alignment. To a certain extent, this movement could be compensated for by adjusting the large bearings that supported each drive shaft, but ultimately geology must win out.

By 2003, the plant was on 'standby' status and was still used, primarily on weekdays, to generate power for industries. In addition, the plant generated power when excess water capacity was available which could not entirely be used by the other Ontario power generation plants in the area such as Sir Adam Beck I and II.

In 2005, after 100 years of continuous power generation, the plant officially ceased generating power.

Figure 17 Interior of the powerhouse

Many people, including myself, believe that the Rankine plant deserves saving as an example of outstanding early power engineering – maybe as a museum to inspire future generations!

It is now incumbent on the Niagara Parks Commission, with Government and private investors to secure a future for Rankine - before neglect and inertia send this fascinating plant to the same fate as befell other early hydro stations.

In the Niagara area, there is one older plant than the Rankine, the DeCew Falls plant located on the Niagara escarpment in St Catharines.

This plant began operation with two 1,500hp units on 26 August 1898 and two 3,000hp units were added in 1900. The plant was completed in 1912 with a total output of 44,600kVA at a "unique" frequency of 66.6Hz. It supplied power to Hamilton several years before Niagara power reached Toronto.

Figure 18 Plaque to the man so important to the development of the Adams and Rankine stations - on the end wall of the Rankine powerhouse

The plant was bought by Ontario Hydro in 1930 and converted to 60Hz operation. It still operates today making it the oldest power plant in Niagara.

Later hydro developments at Niagara

Dwarfing the earlier pioneering plants, the Robert Moses plant has an installed capacity of 2,675MW and the Adam Beck stations 1,997MW. Since such large volumes of water are consumed by these stations, electricity production can be constrained at times to prevent detracting from the spectacle of the falls - as it is a tourist hotspot.

The infamous November 1965 blackout of Ontario and several US states occurred after maintenance personnel

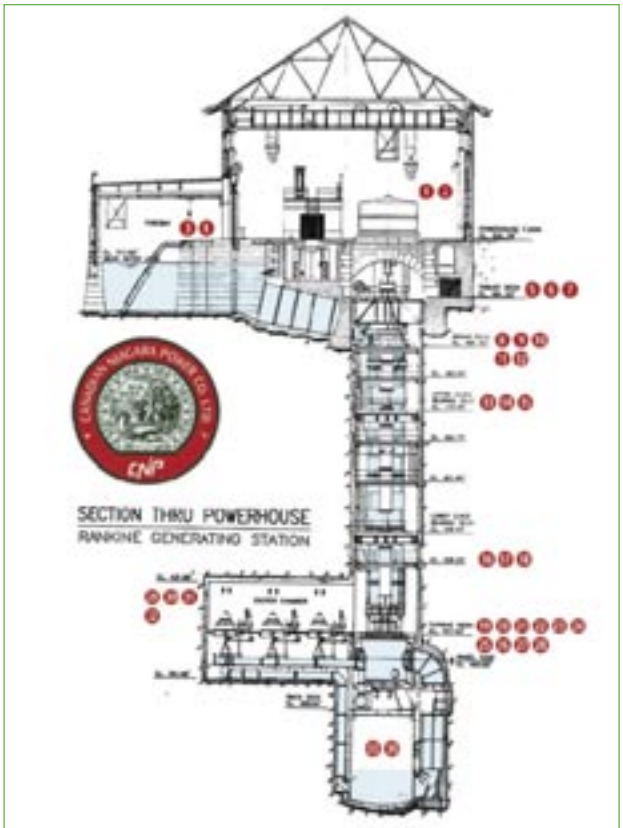

Figure 19 The vertical extent of the William B Rankine Generating Station, from the surface powerhouse and forebay to the bottom of the station's 130-feet deep wheelpit

Figure 20 Tarpaulins cover mothballed generators and electrical equipment - "current" situation in William B Rankine powerhouse

incorrectly set a protective relay on one of the transmission lines from the Sir Adam Beck Station No II. The faulty relay later tripped open causing a series of cascade failures which affected over 30 million people for up to 12 hours!

Conclusion

The history of the first power plants to capture some of the energy of the waterfalls at Niagara involve a number of significant developments in technology, not least the adoption of Alternating Current generation and transmission - of which Nikola Tesla was an early proponent. This took place towards the end of the 19th century and the beginning of the 20th century at the dawn of what we could now call the "First Electric Age".

From the current perspective of the first two decades of the 21st century, with new technologies developing in renewable forms of generation and energy storage – together with the

Figure 21 Aerial view of Sir Adam Beck I & II, and Robert Moses Power Plant downstream of the Falls - Sir Adam Beck I & II on the Canadian side, and Robert Moses on the US

Figure 22 The name of Canadian Niagara Power together with the flag is prominent on the front face of the power house

pressing need to de-carbonise all our energy systems – perhaps we are at the dawn of the "Second Electric Age"?

They were clearly just as confused as to which technologies or combination of technologies would be the most successful then - as we are now - when trying to reduce carbon release and local pollution. ■

Biographies

William Birch Rankine (4 January 1858–30 September 1905). He was an attorney, promoter and company director, was born in Oswego, New York, the son of James Rankine, an Episcopal clergyman, and Fanny Meek. His father was a cousin of the famous Scottish engineer William John Macquorn Rankine.

He read law in the office of Augustus Porter of Niagara Falls, and was admitted to the bar of the State of New York in 1880 and at once entered into the active practice of his profession in New York city. Mr Rankine was a brilliant and successful lawyer. In 1889 he became one of the incorporators of the Cataract Construction Company.

Prof William John Macquorn Rankine FRSE FRS LLD (5 July 1820–24 December 1872). A Scottish mechanical engineer who also contributed to civil engineering, physics and mathematics.

He was a founding contributor, with Rudolf Clausius and William Thomson (Lord Kelvin), to the science of thermodynamics, particularly focusing on the first of the three thermodynamic laws. He developed the Rankine scale, an equivalent to the Kelvin scale of temperature, but in degrees Fahrenheit rather than centigrade – as well as developing the thermodynamic understanding of steam power cycles with the Rankine cycle named after him.

So the University of Glasgow was a hotbed of power thermodynamics – and also earlier produced a chap called Watt!

Charles Gordon Curtis (Boston April 1860 - March 1953). US inventor who devised a steam turbine widely used in electric power plants and in marine propulsion. He was a patent lawyer for eight years.

In 1896, five years after it was patented, Curtis sold the rights to the turbine to General Electric. An agreement with GE in 1897 allowed Curtis space and personnel to develop the turbine for commercial use, and GE the rights to manufacture the turbines. He continued working at GE for three years directing turbine development.

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The Author:

Mike Raine retired from Rolls-Royce in 2001 after a long career involved in applying gas turbines for industrial and marine uses – predominantly for electrical generation.

This involved projects all around the world including working with other OEM companies abroad in developing products, culminating in becoming Engineering Director of RR Industrial Power Systems.

Since "retirement" he has been an engineering consultant specialising, in newer energy systems, and Director General of IDGTE, allowing him to retain his interest in development in the rapidly changing energy scene.

Mike is a member of IMechE and a Fellow of IDGTE.